MODELING FOG OIL OBSCURANT SMOKE PENETRATION INTO SIMULATED TORTOISE BURROWS

M. A. Guelta*
U.S. Army RDECOM - Edgewood Chemical Biological Center
Aberdeen Proving Ground, MD 21010-5424

H. E. Balbach
Engineer Research Development Center – Construction Engineering Research Laboratory
Champaign, IL 61826-9005

ABSTRACT

The gopher tortoise (*Gopherus polyphemus*), found on many military installations, is threatened in its westernmost distribution and at risk everywhere else. On installations where troop readiness training is conducted, an important component of realistic troop readiness training is the generation of obscurant material and the conduct of maneuvers under obscurant cover. Fog oil has long been deployed for visual obscuration training, and the effect of such obscurants on this species is unknown. As a preliminary step prior to instituting toxicological studies, a laboratory simulation was performed of the capability of the fog oil smoke to penetrate the burrow of the gopher tortoise. The fog oil smoke did not enter the simulated tortoise burrow in significant concentrations. This suggests that tortoise burrows do not need to be studied in situ, and that tortoises may be considered protected while in the burrow.

1. INTRODUCTION

1.1 The Problem

Domestic Army installations, when combined with installations of other U.S. military services, total more than 25 million acres (about 10 million hectares). Among this land area are significant parcels in which the intensity of use is low enough, or infrequent enough, to allow the continuation of populations of species which, although originally common, are now much less common outside the installation than within it. Some of these species are designated as endangered or threatened under the Endangered Species Act of 1973 (Public Law 93-205; 16 U.S. Code 1531 et seq., as amended) (ESA). Other species are not yet so designated, but they are considered locally or regionally threatened or of special concern ("at risk"). Army installation managers are regularly called upon to accommodate the needs of such at risk species to the greatest degree possible without compromising the essential mission activities of the base.

One of these "species at risk" is the gopher tortoise (*Gopherus polyphemus*), a large, land-dwelling turtle that is or was found in parts of six southeastern states. The tortoise digs its burrows in sandy soils where the forest canopy is open enough to allow the sun to reach the surface. In the past, there was a strong association with pine forests, especially longleaf pine (*Pinus palustris*). With the advent of plantation forestry, as well as loss of habitat to urbanization, populations are declining throughout their range. One report (Auffenberg and Franz 1982) estimated that in the past 100 years gopher tortoise populations have declined by 80 percent. This significant decline resulted in the species being listed by the Fish and Wildlife Service (FWS) as "Threatened" in Louisiana, Mississippi, and west of the Tombigbee and Mobile Rivers in Alabama (Federal Register, July 7, 1987). The tortoise is being studied as a part of the Army Threatened and Endangered Species (TES) research program due to its potential for causing training conflicts at locations within the nonlisted (eastern) population were it to be listed, as was requested by a petition in January 2006 (Save Our Big Scrub, Inc. and Wild South 2006). At least 18 military bases are known to have gopher tortoises (Wilson et al. 1997).

Among the training activities that occur in or near the gopher tortoise habitat is troop preparedness training and the field testing of generating equipment that releases fog oil smoke into the atmosphere. Obscurants have long been used to mask movements of troops and mechanized equipment. Of the conventional smokes, the white smoke generated from vaporization and condensation of liquid fog oil is an effective obscurant in the visible range. It is the most heavily used obscurant for troop training because of its low cost, ease of handling and smoke generation, dispersion characteristics, and safety (Eberhard et al. 1989).

SGF-2 fog oil (FO) is the obscurant used most frequently for military training. The FO procured by the U.S. military has undergone a modified refining process to reduce quantities of potentially harmful components. Although called a smoke because of its appearance when generated in the field, it is not burned but rather vaporized and disseminated by recondensation as the vapors cool in the air. Airborne FO droplets have a mass median aerodynamic diameter (MMAD) typically between 0.9

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and 1.9 µm (Driver et al. 1993), a size range that deposits within the lung and air sacs of birds (Driver et al. 1990).

However, the effects of airborne fog oil on wildlife are poorly known, or unknown. This lack of definitive knowledge has resulted in an Army research focus on this topic for the past several years. It was originally determined to be important to examine potential adverse effects in birds because they are often more sensitive to airborne pollutants than mammals, have high public visibility, and are used as bioindicators of ecosystem health. This resulted in a series of studies that were a part of the Army TES research program (Getz et al. 1996). This research resulted in a series of technical reports examining the effects of fog oil smoke on various avian species that served as surrogates for the endangered red-cockaded woodpecker (*Picoides borealis*) (Driver et al., 2002a, 2002b, 2004, 2005). Overall, the conclusion of this series of studies was that fog oil vapors posed little direct hazard to altricial avian species, including the red-cockaded woodpecker and other birds in the same general size class (ca 50 g body mass). One cannot extrapolate, however, from these studies to the gopher tortoise due to extremely great differences in metabolism and lung function between the tortoise and the birds studied.

1.2 Objective

Because it is not known whether fog oil smoke has any health effect on the gopher tortoise, the first objective of this research program was to attempt to demonstrate, in a nonliving simulated environment, the degree to which fog oil smoke was able to penetrate into the living space of this species. With this knowledge in hand, a decision could be made about whether it was necessary to pursue further toxicological studies with the species to determine any actual health hazard related to exposure to fog oil smoke usage in Army training activities. It would be assumed that tortoises on the ground surface would be exposed to ambient levels of the smoke.

1.3 Scope

This study was limited to the measurement of the penetration of fog oil smoke into simulated gopher tortoise burrows. The "habitat" was constructed of corrugated plastic drainage pipe. The study took place in the wind tunnel facility of the Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD. No animals, living or dead, were involved at any time. The desert tortoise (*G. agassizii*) is a closely related tortoise whose habitat is in deserts of southwestern California and adjacent Nevada, Arizona, and Utah. Although not a focus of the present study, it is likely that some or all of the physical principles examined also would apply to that tortoise in its habitat.

1.4 Approach

The "habitat" evaluated for the gopher tortoise was the burrow, a tunnel from 3 to 6 m or more long, which is dug into the soil, and descends at a moderate angle until it is 2 to 3 m below the surface. A simulated habitat that closely approximated the burrow was constructed. Fog oil smoke was generated in a controlled, laboratory setting in which the concentration could be varied and the opening of the "habitat" could be placed in the flow of smoke-laden air. Detailed measurements were taken of the concentration of smoke at several locations within the simulated habitat, and these measurements were compared to the ambient ("challenge") concentration within the tunnel at that time. Comparisons were also made of the level of penetration experienced when the stream of smoke was directed across the habitat opening at different orientations and at different windspeeds.

2. BACKGROUND

Concerns over potential effects to TES from activities at U.S. Army training sites have sparked much debate, field study, and closure or limitations of activities on Army lands. Range managers often must balance the requirements of troop training exercises and equipment testing against the need to protect individual and/or populations of TES. The use of battlefield smokes for marking and screening represents a challenge in that the smokes not only affect the immediate area of application, but they also affect any areas down wind of the test site.

Testing and training sites can encompass large areas of relatively undisturbed open range and wooded areas. These sites have become valuable for existing and displaced animal species, including populations of TES. Therefore, the protection of these TES has fallen more under the stewardship of the Army than any other military service or public group. The ability to manage and make decisions regarding training and testing requirements versus TES stewardship requires insight into species habitat requirements, lifecycle, seasonality of testing and training, and effect of testing, if any, on the species of concern. Getz et al. (1996) conducted a preliminary assessment of the potential impact of fog oil smoke on selected TES. Part of their findings and recommendations included the testing of certain assumptions regarding the protection an underground burrow may afford its occupants. Specifically mentioned was the gopher tortoise burrow, which is the focus of this study.

The gopher tortoise has a current distribution in the southeast United States from southernmost South Carolina, through Georgia, west to extreme eastern Louisiana, and south throughout Florida. The gopher tortoise digs underground burrows in friable, sandy soils

and can extend up to 6 to 7 m or more in length. Other ground-dwelling animals, including many at-risk species, also frequent these burrows. Generally, it has been thought that these burrows would provide the inhabitants with protection from exposure to smokes used at test and training sites. There has been some controversy, however, as to the degree of protection. The lack of test data to support ideas of any protection provided by the underground burrow has led to proposed testing of underground burrows.

The greatest threat to the gopher tortoise is loss of habitat. Therefore, the gopher tortoise is frequently found on government lands, including Army testing and training sites, where habitat loss has been much less than on surrounding lands. Wilson et al. (1997) reported active gopher tortoise burrows on 19 military testing and training sites throughout the southeastern United States. The gopher tortoise and many vertebrate species make use of the burrows for shelter from temperature extremes and predators. The gopher tortoise excavates burrows that are generally at least 5 m in length and of a diameter that allows them to turn around. A single tortoise may use several burrows simultaneously over its normal range, although females, especially, appear to have preferred burrows to which they return a majority of the time.

Generally, the collection of field data can prove challenging and costly. Site characteristics, inclement weather, and logistics of conducting fieldwork often greatly increase the costs and decrease the quality and completeness of data collected. The potential costs of conducting field tests can place desirable programs on a “back burner” until an impact to range use or testing has been realized. An alternative is to first conduct initial testing under the more controlled conditions of a laboratory or engineered study using models that closely imitate conditions that may be seen in the field. Decisions then may better be made to determine which elements need study under field conditions.

This study was designed to gather data to assess the potential of penetration of the large-area screening smoke FO into a model burrow of the gopher tortoise. During this study, models were constructed to closely approximate the geometry of burrows observed in the field. Fog oil smoke was generated at concentrations that are regularly used in field exercises and presented to the burrow entrance at wind speeds and orientations that represent field conditions. These conditions included three wind speeds from 4 to 12 mph; wind orientations of 0°, 90°, and 180°, and obscurant smoke concentrations from 50 to 300 mg/m^3.

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3. METHODS

3.1 Tortoise Burrow

The simulated tortoise burrow was constructed using corrugated 20-cm (8-in.) diameter plastic drainpipe and 20-cm (8-in.), diameter dryer vent hose. This diameter was selected as being reasonably close to the functional size of the burrow of a mature tortoise. Although it is recognized that the cross-section of a burrow is not round, the physical factors relating to air movement are believed to be similar enough to not significantly affect the validity of the measurements obtained.

The opening to the model burrow was fabricated using 6-mm (¼-in.) plywood, expanded metal screening, and plaster of Paris (Figure 1). The burrow opening was designed to simulate the depression made by a tortoise at the entrance to the burrow. The burrow of a desert tortoise is generally similar, although the burrow usually is shorter and less deep, thought to be a reflection of the fact that the desert soils often are stony and more difficult to excavate. The model used here also should be relevant to desert tortoise burrow smoke penetration potential.

Figure 1. Entrance of modeled tortoise burrow.

The entrance to the model burrow was constructed on a moveable platform that was then placed into a wind tunnel test section. The platform was movable to allow several 90° changes in FO air flow challenge orientation (Figure 2). The model burrow was 5 m in length. Aerosol sensors were placed just outside the entrance for challenge FO concentration measurement and 1, 3, and 5 m below the inside opening of the burrow.

The entrance to the burrow gradually sloped to approximately 10 cm (4 in.) below grade. The top of the burrow entrance was slightly below grade, with a mound of simulated soil slightly above grade. This sculpted entrance was fastened to the first section of flexible duct. The duct was connected to a section of corrugated pipe so that the first sensor array was 1 m down the “burrow.”

Additional lengths of flexible duct alternated with sections of drainage pipe so that other sensors were placed at the 3-m and 5-m positions in the simulated burrow (Figure 3).

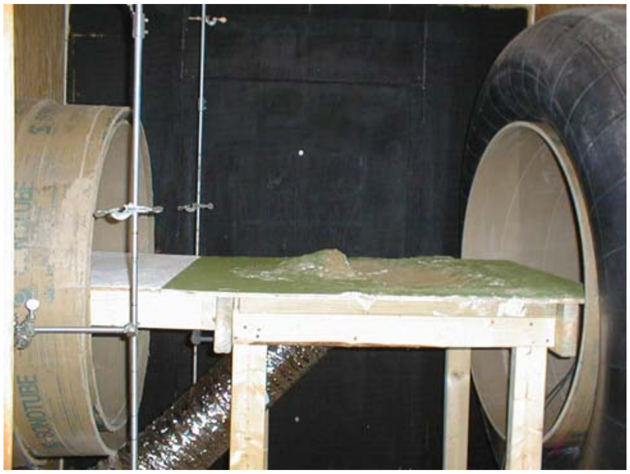

Figure 2.. The model gopher tortoise burrow placed in wind tunnel test section with entrance oriented 180˚ to wind direction (i.e., away from the air flow).

Figure 3. The model gopher tortoise burrow extended through door of the wind tunnel test section with entrance facing 90˚ to wind direction. Each section of black corrugated pipe contains an aerosol sensor. Those at the 3-m and 5-m positions are visible here. The 1-m position is within the chamber.

3.2 Generation of Fog Oil

Fog oil was generated using a pair of small scale smoke generators (S3-G). An S3-G is a gasoline-powered electric generator with a modified exhaust system. This type of small system was developed for the multiple functions of FO generation and generation of portable power to allow for field operation of FO detection equipment, pumps, data loggers, and computer systems. In this study, the equipment was operated using internal electric power sources from the building, and the generated electric power was used to power a high-temperature heat tape, which assisted in vaporization of the FO and helped to keep the exhaust gas in the vaporization chamber above 400˚C.

The modified exhaust/vaporization chamber is comprised of a 3.4-cm (1 ½-in.) diameter by 54-cm (24-in.) long galvanized pipe. Ports in the end of the exhaust allow injection of FO and engine exhaust. The FO is pumped from a holding reservoir and injected into the vaporization chamber by a peristaltic pump. The hot exhaust from the S3-G engine vaporizes the liquid FO and directs it into the wind tunnel inlet. The variable speed of the pump allows control of the amount of FO generated and establishes the challenge FO concentration in the test chamber.

3.3 Aerosol Wind Tunnel

The open-jet aerosol wind tunnel used for testing is operated by the Aerosol Sciences Team, Edgewood Chemical Biological Center, Research and Technology Directorate, of the U.S. Army Research, Development and Engineering Command (Figure 4). The open-jet aerosol wind tunnel test facility (the "OJ") is an open circuit, continuous flow, subsonic wind tunnel. It was designed to conduct evaluations of aerosol collector inlets, but it is easily adapted to other aerodynamic test needs. It features a 1-m diameter open-jet test section, which eliminates wall effects and allows testing of large inlets or objects. The usable jet stream of moving air is then 1.0 m in diameter and 1.2 m long. This allows testing of most sizes of inlets in a velocity range of 4 to 25 mph. The test section area is enclosed by a large plenum approximately a 2.4-m (8-ft) cube at negative pressure with respect to atmosphere. This prevents aerosol leakage into the lab and provides a large area for viewing windows and lighting effects. This tunnel is also unique in its implementation of a "generic mixing system" (McFarland et al. 1999) upstream of the test section to assure good aerosol and flow profiles in the test section.

3.4 Measurement of Fog Oil Smoke Concentrations

The FO challenge and penetration concentrations were measured using realtime aerosol sensors (RAS), model 2 (manufactured by Monitoring Instruments for the Environment [MIE] Inc., Billerica, MA). The sensors were calibrated prior to burrow testing using FO generated by the S3-G, and concentrations were measured using gravimetric analysis of open-faced filter samples.

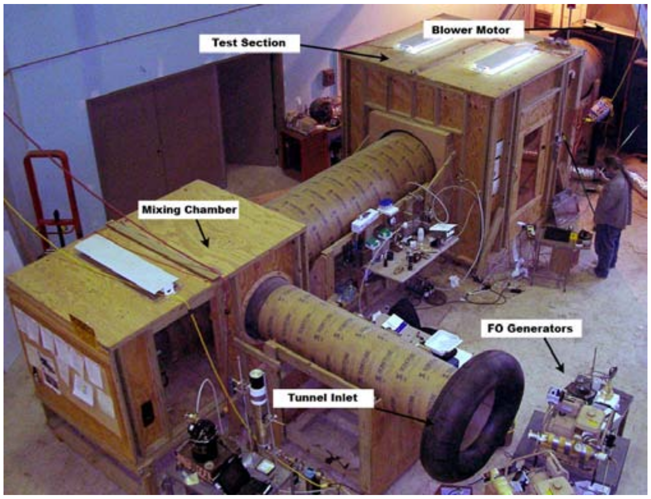

Figure 4. Open jet wind tunnel view from above.

The RAS is a compact airborne particulate concentration transducer with an operation principle based on the detection of scattered electromagnetic radiation in the near infrared. The RAS uses a pulsed GaAlAs (gallium aluminum arsenide) light source, which generates a narrow-band emission centered at 880 nm. This source is operated at an average output power of about 5 mW. The radiation scattered by the airborne particles is sensed over an angular range of approximately 45° to 95° from the forward direction by a silicon-photovoltaic hybrid detector with internal low-noise preamplification. An optical interference-type filter is incorporated to screen out any light whose wavelength differs from that of the source.

Air surrounding the RAS passes freely through an open-ended sensing chamber, and does not need a pump for operation. The scattering sensing parameters have been designed for preferential response to particles in the 0.1 to 10 µm size range. The RAS is manufactured in two concentration ranges, and provides an analog output directly proportional to the concentration of airborne particles. The sensors used for this study have a dynamic range of 0.1 to 1000 mg/m^3. Output gain for each of the four remote air sensors was set to 50 mV using a standard scattering window prior to calibration. The RAS used were calibrated simultaneously using fiber filters sampled at isokenetic flow rates. Calibration equations were calculated for each RAS and used to quantify FO concentrations measured throughout the study.

Access holes just large enough to allow mounting of the aerosol sensors were cut into the corrugated drainpipe. The sensors were positioned so that the sensing volume of the aerosol sensor was as close to the center of the model burrow as possible (Figure 5). The access hole then was sealed to prevent airflow. Sensors were placed at distances of 1, 3, and 5 m from the simulated burrow mouth. The end of the model burrow farthest from the inlet (at the 5-m location) was closed with an end-cap and sealed with expanding foam, mimicking the end of the burrow (Figure 3).

Particle size analysis was performed using an 8-stage, nonviable Anderson Cascade impact sampler, Model Mark II. Smoke was sampled with the impactor during calibration of the RAS. The FO generator exhaust temperature at the time of generation was 400°C.

Figure 5. RAS installed in plastic drain pipe and mounted at end of model gopher tortoise burrow.

3.5 Data Collection

Concentration data from the RAS were collected and saved using an Omega OM-500, multichannel data logger. The OM-500 logs analog out data as millivolts on as many as 5 channels. The OM-500 is a portable unit with battery pack for field operation. Data recorded by the OM-500 were downloaded to its accompanying software after each test run. The software allows for simultaneous display of up to five data sets, an example of which is shown in Figure 6. In this example, the traces from the sensors 1 and 2 were originally recorded in different colors. Data for all test results were entered into an Excel spreadsheet for manipulation and analysis.

3.6 Fog Oil

The FO used in this study was taken from local inventory at Aberdeen Proving Ground. Identification of FO used was taken from the 55-gallon drum label, as follows:

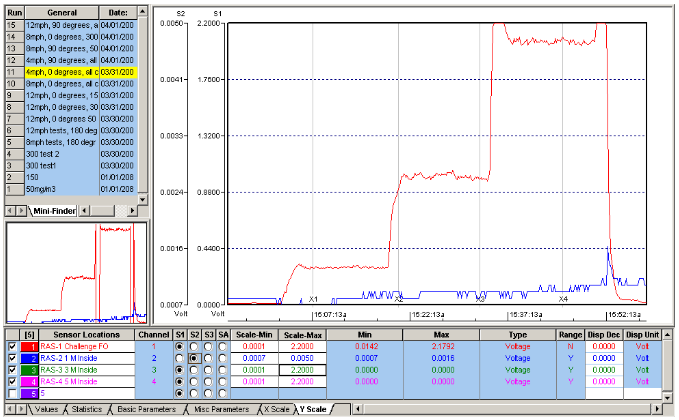

Figure 6. Example screenshot from Omega 5 data logging software. Upper trace is for the challenge concentrations of 50, 150, and 300 mg/m^3. Lower trace is concentration at the 1m sensor.

Data from drum label:

9150-00-261-7895 -- National Stock Number
CAGE/Prime 0A9L8 -- "Commercial And Government Entity"/ Contractor ID number
Fog Oil 1DR Net Wt. 413 lbs.
M 10 08/03 MFD 08/03 -- Manufactured August 2003
Shelf life 3 yrs, re-test in August 06
MIL-PRF-12070F -- Military performance specification number
Flash Pt. 333OF, 167OC
Boiling Pt. 621OF, 327OC
Lot. D2163
SP0450-98-D-4153-0340 -- Contract number from FY98
HOC Industries Inc.
3511 N. Ohio, Wichita, KS 67219-3721

3.7 Test Matrix

The test design was to expose the model to three concentrations of FO, using three different wind speeds at three orientations to wind direction. The model would be put through 27 test series (Table 1). "Challenge" in this usage and in the tables and graphs in this report refers to the concentration in the chamber outside the model during the test.

Table 1. Matrix of FO challenge testing for simulated tortoise burrow.

Wind speed (mph)	Fog Oil concentrations (mg/M^3)	Orientations (degrees to direction)	Tests (count)
4	50, 150, 300	0, 90, 180	9
8	50, 150, 300	0, 90, 180	9
12	50, 150, 300	0, 90, 180	9
Total tests			27

4. RESULTS

4.1 RAS Equipment Calibration

The four aerosol sensors used in this study were calibrated simultaneously by recording RAS output, separately from each sensor in millivolts versus weight of FO collected on glass fiber filters. Calibration equations were determined by linear regression of recorded data. Calibration data are displayed in Figures 7 through 10. RAS-1 (Figure 7) was used throughout the study to record challenge FO concentration.

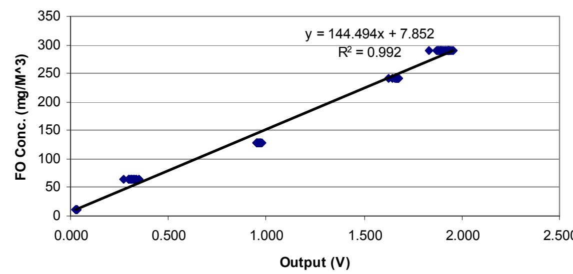

Figure 7. Linear regression calibration of RAS-1.

RAS-2 (Figure 8) was used throughout the study to measure FO concentration 1 m inside the model gopher tortoise burrow.

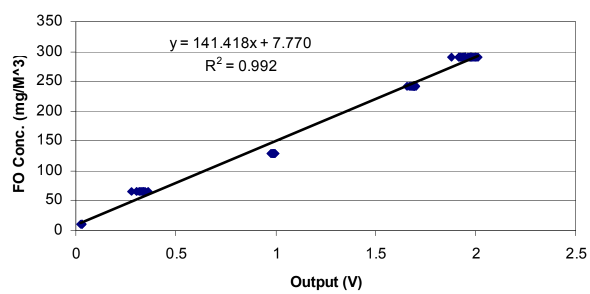

Figure 8. Linear regression calibration of RAS-2.

RAS-3 (Figure 9) was used to measure FO penetration concentrations in the model gopher tortoise burrow at the point 3 m into the model burrow.

RAS-4 (Figure 10) was used to measure FO penetration concentrations in the model gopher tortoise burrow at the point 5 m into the model burrow.

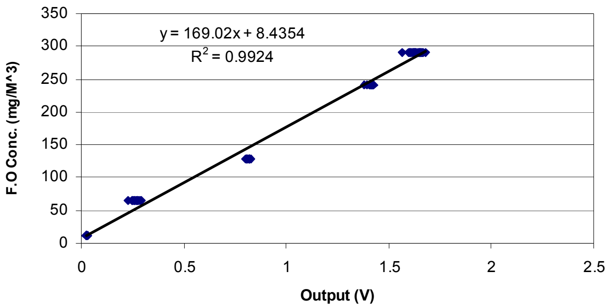

Figure 9. Linear regression calibration of RAS-3.

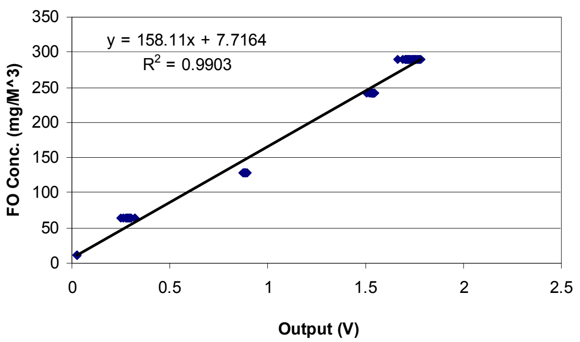

Figure 10. Linear regression calibration of RAS-4.

Challenge FO particle aerodynamic mass mean diameter was measured at 0.58 µm (Figure 11). This particle size falls in the lower range of FO particle sizes reported by Chester 1998, but it is realistic for a freshly generated smoke that was produced at a lower initial plume concentrations. Data were entered into an Excel spreadsheet, and a best fit trend line was added by the program. Figure 11 is a cumulative plot of particle size distribution within the Andersen sampler.

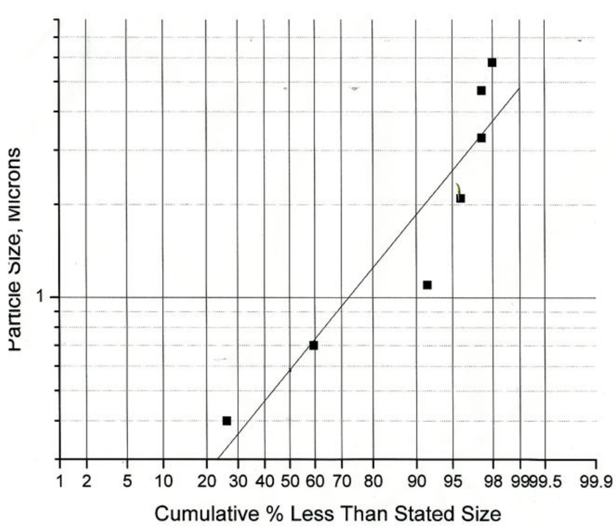

Figure 11. Anderson sampler plot of fog oil particle size distribution.

4.2 Model Tortoise Burrow Data

Fog oil penetration into the model tortoise burrow was minimal for all tests conducted. Table 2 is a summary of the average FO challenge and penetration concentrations measured. Data for model burrow concentrations are displayed only for the 1 m (into the burrow) sensor position. RAS-3 and 4 measurements at positions 3 m and 5 m into the burrow were below detectable levels (less than 1/10,000 of the ambient/challenge concentration) for the entire study and are not presented here.

Table 2. Summaries of mean FO challenge and penetration concentrations measured during testing of the model gopher tortoise burrow.

	Orientation 0 degrees		**Orientation 90 degrees**		**Orientation 180 degrees**	
Wind Speed (mph)	Challenge Conc. (mg/M^3)	Conc @ 1 m inside (mg/M^3)	Challenge Conc. (mg/M^3)	Conc @ 1 m inside (mg/M^3)	Challenge Conc. (mg/M^3)	Conc @ 1m inside (mg/M^3)
4	50.3	0.0	52.4	0.0	51.1	0.0
4	152.4	0.0	152.4	0.1	153.6	0.0
4	305.0	0.0	301.6	0.3	296.2	0.3
8	51.1	0.0	51.4	0.0	51.3	0.0
8	153.4	0.0	152.5	0.1	161.2	0.1
8	304.0	0.0	299.0	0.4	304.7	0.1
12	51.1	0.0	50.8	0.0	51.7	0.0
12	153.2	0.0	152.4	0.2	164.3	0.0
12	265.6	0.1	281.9	0.3	240.8	0.0

CONCLUSIONS AND RECOMMENDATIONS

Based on our results presented in Table 2, it is concluded that smoke-generating activities on Army training and testing lands are not likely to create significant concentrations of fog oil smoke in tortoise burrows. Under the most taxing conditions (i.e., with the airstream blowing directly toward the mouth of the simulated burrow), the smoke concentrations were approximately 0.01 percent of the ambient level, they never exceeded 0.75 percent, and were lower with other burrow mouth orientations.

The conclusion must be that it is not necessary — in further conduct of Army research into potential threats to threatened, endangered, and at-risk species — to conduct field studies of fog oil smoke within tortoise burrows. Both gopher and desert tortoises, however, spend considerable time on the surface while feeding and moving about their habitat during social interaction with

other tortoises. During these periods they would, of course, be exposed to approximately the full concentration of smoke. Should it become necessary to do so, further studies of the effects of fog oil smoke on the tortoises themselves may be required. However, measurements of concentrations within burrows may reasonably be assumed to be very low, approaching zero, and could not represent a significant health threat.

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